Memo

To:	CCB
From:	David Jepsen and Spiro Spiliopoulos
Date:	June 23, 2000
Subject:	Revised procedures for DFX event-characterization amplitude measurements
Sponsor:	Bob North
CC:	

Abstract

This memo proposes the inclusion of revised procedures for calculating DFX event-characterization amplitudes in the PIDC7.0 software release. Four significant changes are proposed:

(i) Time windows employed to calculate DFX event characterization amplitude measurements have been modified so that they more accurately represent the time in which the regional phases are expected/observed and to minimise the interference of phases and noise.

(ii) An additional five frequency bands for calculating Lg amplitudes at low frequencies have been set up so that research can begin on the mblg magnitude procedure.

(iii) Amplitude measurements have been extended to all events whose 95% depth interval falls within the crust.

(iv) Removal of tapering in the beam normalization function in routine libbeam/beam.c when `nelem=1` has been implemented, to minimise anomalous beams being formed.

These changes will provide both improved and necessary additional amplitude estimates for use in event screening.

Statement of Objective

To improve the accuracy and reliability of event characterization amplitudes, and to provide measurements to be used in the development of Mb(Lg).

Summary of Proposed Changes

1. Existing amplitude time windows have been modified so that more accurate and reliable

amplitudes are calculated. The depth to which these measurements are made has been changed from 30 to 35km (in line with iaspei91 crustal depth of 35km), and also extended to events whose 95% depth confidence interval falls within the crust. Pn & Pg and Sn & Lg amplitude measurements in the first 3 degrees have been replaced by maximum P-signal and S-signal amplitudes respectively. Existing amplitude measurements that are calculated in predicted time windows and are within 3 degrees of the event, need to be removed. This will remove the problem of overlapping regional phases that is prominent with the amplitude measurements out to 3 degrees. Also varying the observed window length with distance will minimise overlap problems.

2. These revised procedures will provide regional phase amplitude measurements required for the development of an IDC mblg magnitude procedure. Current event-characterization processing does not measure Lg amplitudes in bandpasses that can be compared with published work on mblg. Additional filter bands have been proposed to provide these Lg amplitudes with sufficient lead time to permit development of a regional mblg magnitude.

3. The routine src/common/libsrc/libbeam/beam.c has been modified so that the beam normalization function is not tapered for `nelem=1`. This bug fix improves the accuracy of the beams generated and hence the accuracy of the resulting amplitudes.

Full details of modifications and additions to source, par and scheme files are described in Appendix B

Expected Benefits

1. More accurate and reliable amplitude measurements will be computed. This will provide greater confidence of their use in event screening procedures.

2. Amplitudes will be calculated for all events that could possibly originate in the crust. The extra measurements could provide valuable information for regional event screening.

3. A body of knowledge will be collected to permit development of a regional mblg procedure. Mblg has been found to be a portable robust regional magnitude in a diverse set of tectonic environments.

4. The process to form beams is more reliable.

Possible Risks and Dependencies

There is no known added risk in the accuracy of measurements being made, except that the time windows employed for possible crustal events (i.e. REB depth > 35km whose depth interval is within the crust) may not be appropriate and/or not have any regional phases. However ensuring that the amplitudes exceed an SNR threshold will overcome most of these problems.

More storage space needs to be allocated to the appropriate oracle database amplitude table to account for the extra regional phase amplitude measurements being calculated. The number of entries will grow by around 50%, which equates to an additional 12Kbytes/day of storage space.

There are no problems with the process being too CPU intensive or failing to complete.

Summary of Testing

The changes were tested offline on a 14 day dataset spanning the period Mar 26 - April 8, 1996. There are 994 events in the REB for this period. There were no failures in the processing and it took on average about 2.5 hours to calculate all the amplitude measurements for a day, which is not significantly different from the processing time to calculate these measurements previously (see CCB-PRO-98/07). Thorough details of the testing on this fixed dataset can be found in Appendix A.

In terms of validation of the amplitude measurements, it was found that the amplitudes are more accurate and that the new measurements are seismologically consistent. A thorough evaluation of these measurements is detailed in Appendix A.

Testing of the new software was also performed on the pIDC testbed. The Integration Test Plan and Report can be found in Appendix C. In summary, all procedures on the testbed completed successfully and all expected amplitudes were calculated.

Schedule and Plan for implementation

This proposal is one part of PIDC 7.0. Installation of PIDC 7.0 will follow the Plan for Implementing PIDC 7.0 into PIDC Operations (Skov et al., 2000). One exception is that the existing predicted amplitude measurements that are within 3 degrees of an event need to be removed in a separate <u>one-off</u> process. The two SQL commands to be run on the REB account are:

```
delete from amplitude where parid in
(select p.parid from parrival p, assoc a
where p.orid=a.orid
and p.sta=a.sta
and a.delta <= 3.0);
```

```
delete from parrival where parid in
(select p.parid from parrival p, assoc a
where p.orid=a.orid
and p.sta=a.sta
and a.delta <= 3.0);
```

Costs and Resources Required for Implementation

It is estimated that a maximum of 1 person day of Operations will be required for understanding and implementation of this part of Release3. No additional costs will be incurred.

References

CCB-PRO-98/07: PIDC 6.0: Event Characterization, 6 March 1998

Skov, M., Bahavar, M., and A. Ben-Pazi, Plan for Implementing PIDC 7.0 into PIDC Operations, CMR Technical Report CMR-00/10, 2000.

Appendix A: Validation of new and updated amplitude measurements

In this appendix, details on the performance of calculating the amplitude measurements on a Fixed Dataset, and the seismological evaluation of the new and updated measurements are described.

1. Fixed Dataset Performance

The DFX event characterization process was run on all REB events in the 2 week period March 26 - April 8, 1996 in the same way as it is performed in Operations. On average it was found that it took 2.5 hours to complete a 24 hour period, which is not significantly different to the processing time to calculate these measurements previously (see CCB-PRO-98/07). The actual processing time for each 24 hour period varied (from 111 to 246 minutes), and depended on the number events in that day.

There were no crashes of the process due to memory/coding problems, and there was a 100% completion rate.

2. Validation of new and updated amplitude measurements

2.1 Modified time windows

2.1.1 Requirement

Two types of amplitude measurements are made, amplitudes of observed regional phases, and amplitudes in predicted time windows based on a combination of Iaspei travel times and group velocities of the regional phases. The latter measurements are calculated to provide an upper amplitude limit of a regional phase that may not have been picked by an analyst. The predicted windows are normally much longer than the observed windows, hence if the maximum amplitude does not fall in the same time window as the observed one, the amplitudes will differ. This is the reason why observed amplitudes are used in precedent to the theoretical measurements.

In a comparison of observed regional phase travel times to the predicted time windows, for events during the period Apr-Oct 98 (see fig. 1), it is seen that while the fit is good, it could be vastly improved. Firstly the overlap of Pg & Pn and Sn & Lg phases at short distances needs to be addressed, the predicted Sn window is both too late and crosses into the Lg domain, and the predicted Pg window is not long enough. Implementation of new predicted time windows should result in more reliable amplitudes being calculated.

The window length for calculating amplitudes for observed phases is 20 seconds long. At close distances this is inappropriate as interference of other regional phases may occur. So the window lengths need to be varied with distance.

2.1.2 Proposed Changes to time windows

The necessary changes to the predicted and observed time windows are as follows:

(1) Replace Pn & Pg and Sn & Lg amplitude measurements in the first 3 degrees by maximum P-signal and S-signal amplitudes respectively. The predicted Pmax and Smax windows are:

Pmax: 8s before the theoretical arrival time of Pn to a group velocity of 5.8km/s + 5 seconds.

Smax: 5s before the theoretical arrival time of Sn to a group velocity of 3.0 km/s + 5 seconds.

(2) Change the Sn predicted time window from "5sec before the theoretical arrival time and a 20sec duration" to "10/20sec (3-7/7-20degrees respectively) before the theoretical arrival time to a group velocity of 3.8km/s".

(3) Lengthen the predicted Pg window from a group velocity of 5.8km/s to 5.8km/s + 5 sec

(4) Vary the window length for the observed regional phases from 20 seconds to :

Delta (degrees)	window length (seconds)
0-5	6

5-6	11
>6	16

Exact details of the changes can be found in Appendix B by viewing file DFX-evch-ti.par

2.1.3 Seismological Evaluation

By superimposing the observed regional phase travel times of REB events during the period April-Oct 98 onto the new predicted travel time windows (see fig. 2), it is evident that the fit has markedly improved. However due to event mislocations, anomalous paths and phase misidentifications, not all the observed arrivals fit the new predicted travel-time windows. Some Pn and Sn phases come in early and some overlap of Pn & Pg phases remains. Likewise for observed regional phases in the test period Mar26-Apr8, 1996 (figure 3), all essentially fit within the new predicted time windows.

There is strong evidence that the new Pg and Sn windows are better. An analysis of the SNR ratio improvement of the predicted amplitude measurements for Pg and Sn (table 1), shows that the number of arrivals with a SNR >= 2 has significantly improved for Sn and slightly with Pg.

	Existing windows	New windows
% Sn phases with SNR >= 2	33%	54%
% Pg phases with SNR >= 2	65%	68%

Table 1: Percentage of Sn and Pg phases with SNR >= 2 for both the existing and new predicted time windows. The data spans the period March 26 - April 8, 1996.

Pmax and Smax amplitude measurements are shown in figure 4 as log(amp) - ml versus distance. The measurements appear to be seismologically consistent in that they are in the expected range and log(amp) - ml falls off with distance (clearly seen on Pmax plot).

An analysis of the travel time differences of Pn & Pg and Sn & Lg versus distance, for REB events in the period March 26 - April 8, 1996 (figures 5a & b), support the change from a standard observed window length of 20 seconds to a varying window length with distance, as specified in section 2.1.2.

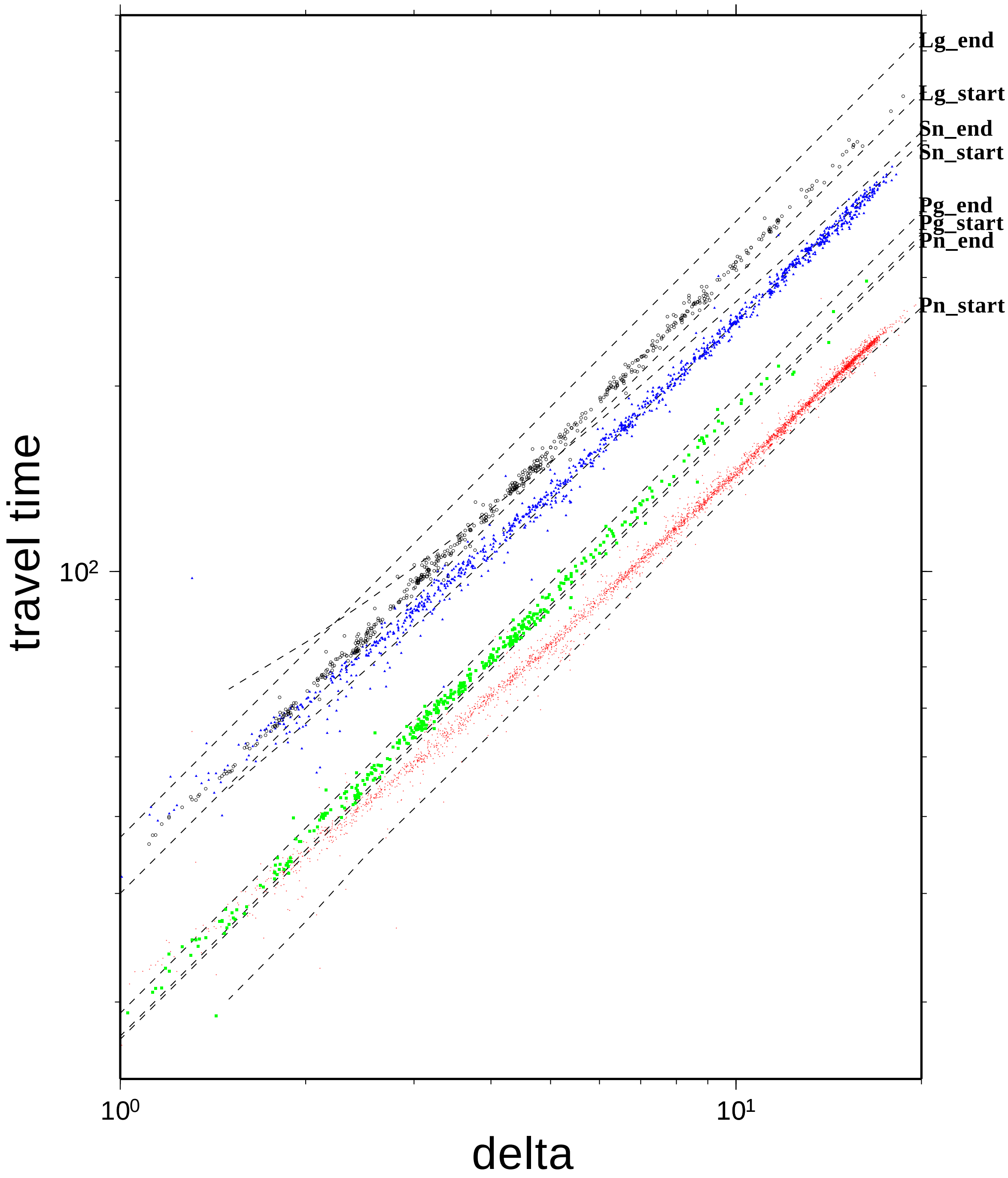

Figure 1: Predicted time windows of regional phases plotted as a function of travel time versus distance, overlayen by the analyst picks: Pn (red), Pg (green), Sn (blue) and Lg (black). The data span the period Apr98-Oct98.

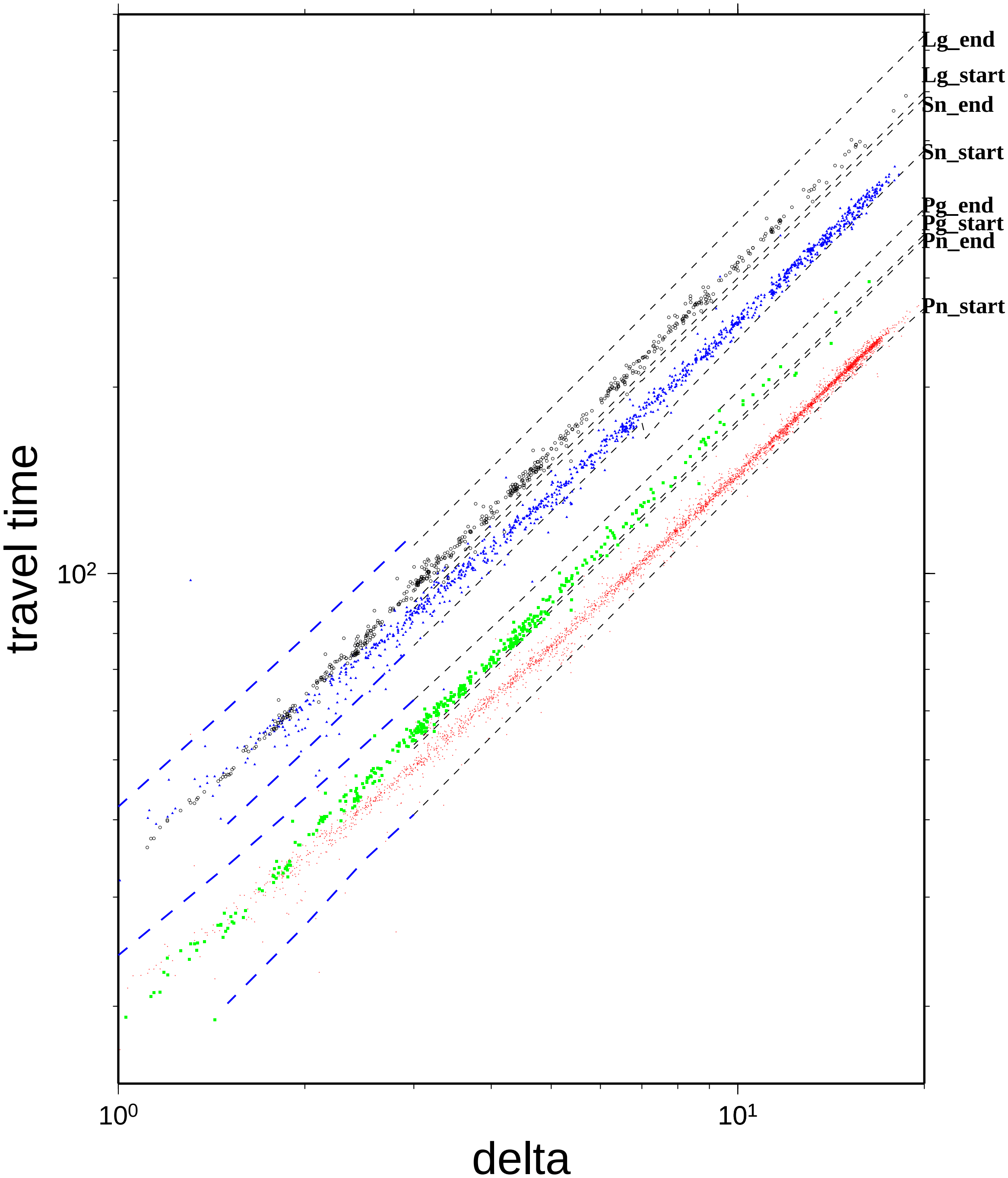

Figure 2: New Predicted time windows of regional phases plotted as a function of travel time versus distance, overlayen by the analyst picks: Pn (red), Pg (green), Sn (blue) and Lg (black). The data span the period Apr98-Oct98.

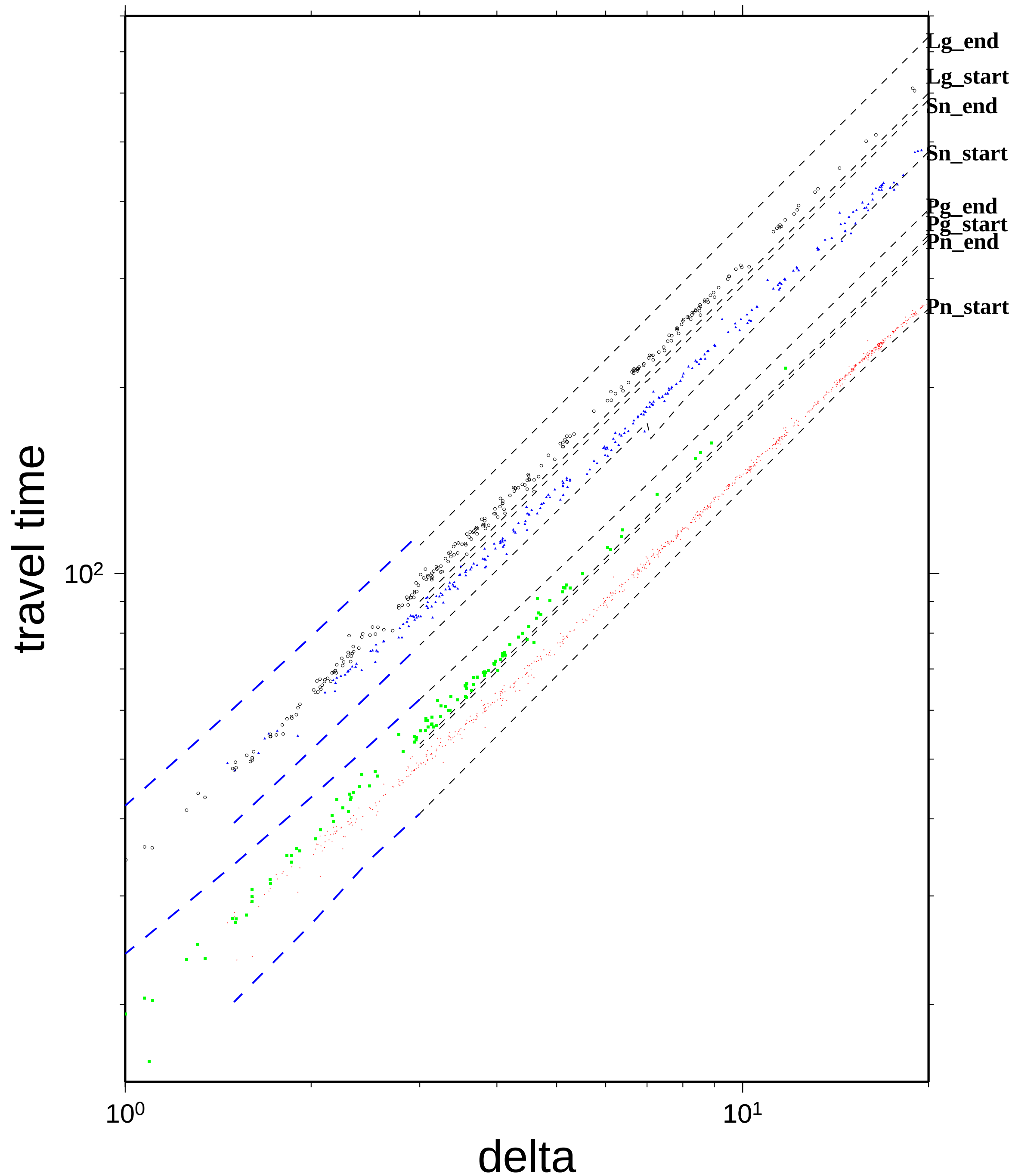

Figure 3: New Predicted time windows of regional phases plotted as a function of travel time versus distance, overlayen by the analyst picks: Pn (red), Pg (green), Sn (blue) and Lg (black). The data span the period 1996086-1996099.

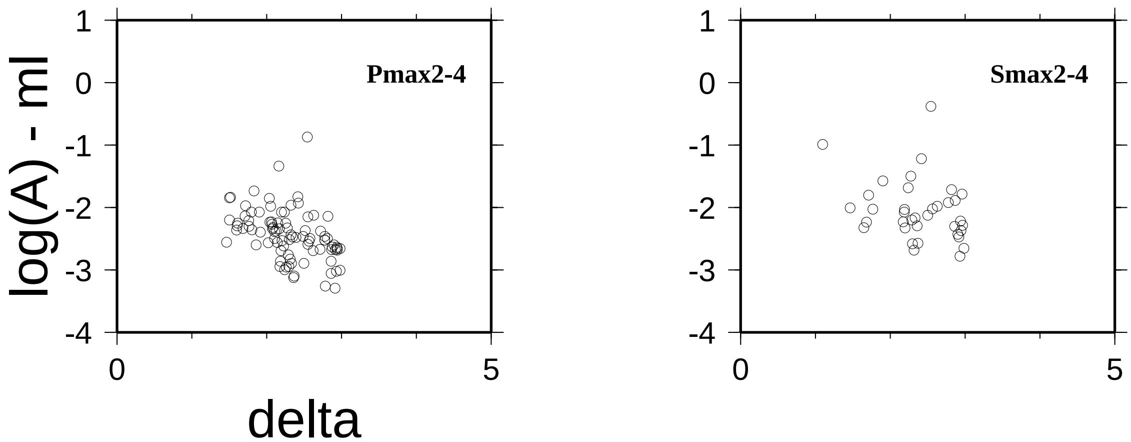

Figure 4: Plots of log(amplitude) – ml versus distance for theoertical Pmax and Smax amplitudes in frequency band 2.4 Hz, with SNR > 2. The data span the period: March 26 - Apr 8, 1996.

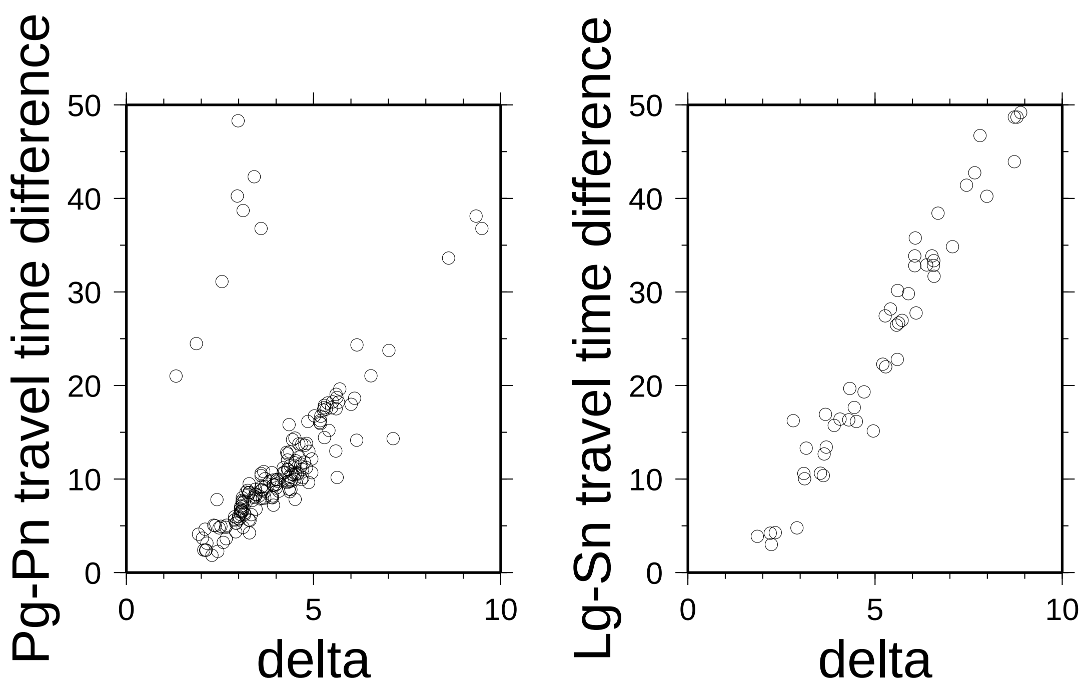

Figure 5: Travel time differences of (a) Pg-Pn and (b) Lg-Sn for REB events in the period March 26 - Apr 8, 1996.

2.2. Additional regional phase time-domain amplitude measurements

2.2.1 Requirement

The current system measures absolute maximum amplitudes on rms coherent vertical beams for Pn, Pg, Sn and Lg regional phases in the frequency bands 2-4, 4-6, 6-8, 8-10, 10-12 and 12-14Hz. These bands do not correspond to frequency bands historically used for mblg estimation. Mblg has historically been measured near 1Hz (cf. Nuttli, 1973; Patton, 1988; Mayeda, 1993) or in a somewhat broader frequency band surrounding 1Hz. (cf. Ringdal, 1983; Hansen et al., 1990). The Lg magnitudes measured near 1Hz have been shown by these prior studies to provide consistent measures of event size and to correlate with nuclear explosion yields (e.g. Nuttli, 1973, 1986a,b; Patton, 1988; Hansen et al., 1990). Measurements of Lg magnitudes from the IDC in a frequency band near 1Hz will provide a baseline for comparison with historical Lg magnitude measurements (mb(Lg)), and alternative measures of Lg magnitudes, which may incorporate higher frequency signals at some future date.

The current frequency bands used for calculating amplitudes for Lg need to be extended to include the following: 0.71-1.41, 0.75-1.25, 0.5-1.0, 1.0-2.0 and 0.5-2.0Hz. This will enable researchers to determine which frequency band will become the standard band for estimating mblg.

Amplitude measurements for observed Pn, Pg and Sn phases are also made for ease of computation, and they may assist in the comparison of low quality hand-digitised records where high frequency information is non-existent.

2.2.2 Method of computation

Theoretical and observed amplitudes for the new frequency bands are calculated in the same way as for their higher frequency counterparts (see CCB-960702 and CCB_PRO-98/07 for details).

2.2.3 Seismological Evaluation

Amplitude measurements for observed Lg in the 0.5-2, 0.5-1.0, 1-2, 0.75-1.25 and 0.71-1.41Hz frequency bands are shown in figure 6, for events in the period March 26 - April 8, 1996. The measurements appear to be seismologically consistent in that (1) the amplitude decreases with distance, (2) the attenuation curve is of the right shape. The attenuation curves were provided by Bennett (Maxwell), which are preliminary estimates based on theoretical and observed measurements at station CMAR. The preliminary attenuation relationship is of the form

$$(\log A - ml) = k1 - 0.833 \log R - 0.389\,[R/Q(avg)]$$

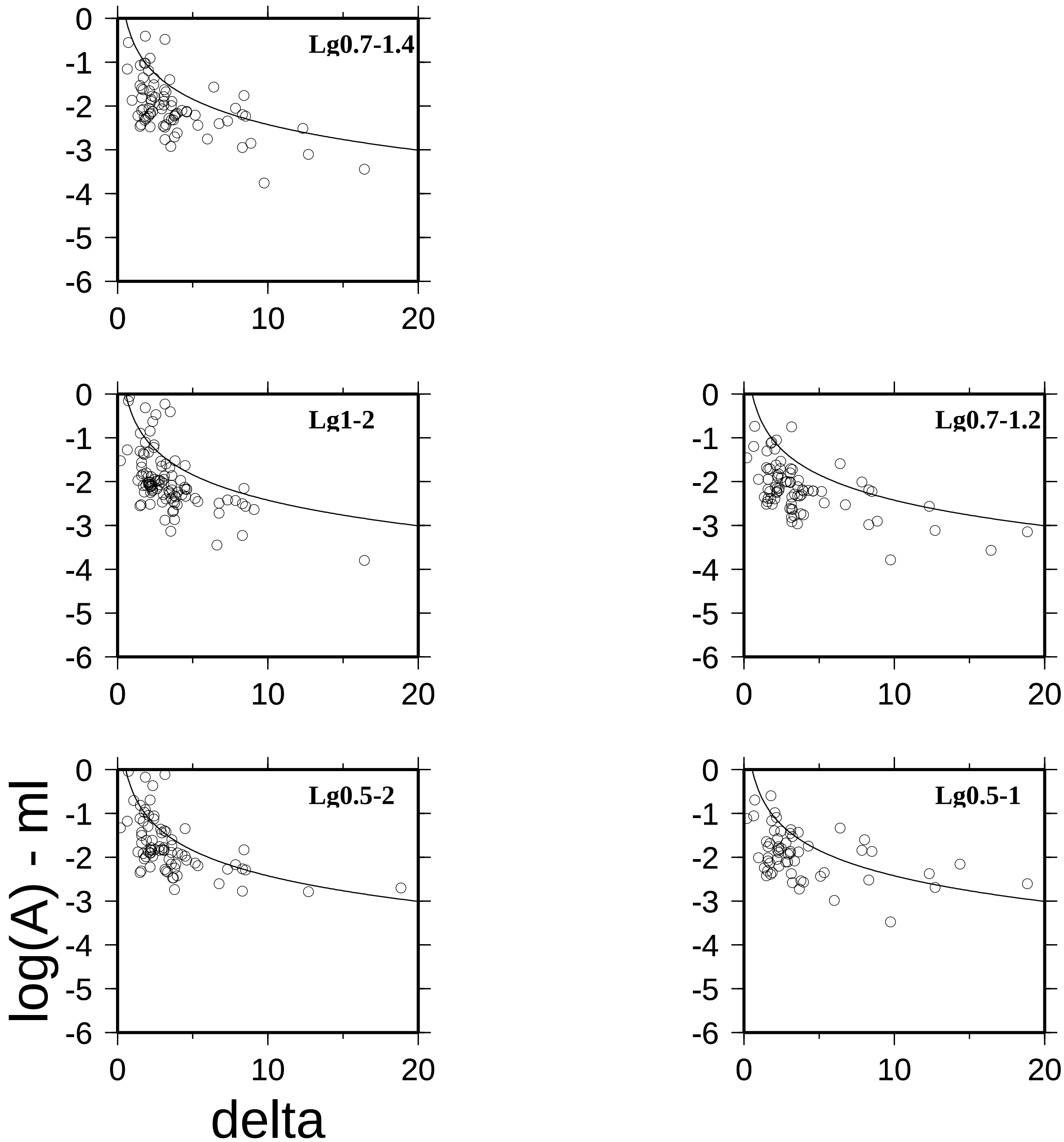

Figure 6: Plots of log(amplitude) – ml versus distance for observed Lg, in frequency bands 0.5-2, 0.5-1, 1-2, 0.7-1.2 & 0.7-1.4Hz, with SNR > 2.The data span the period: March 26 - Apr 8, 1996.

In this case, the scaling constant k1 is set to -0.5, and Q(avg) = 650, and R is in degrees.

2.3. Extend depth to which regional amplitude measurements are made

2.3.1 Requirement

Event screening of regional events will require the use of regional phase amplitudes. Currently, amplitudes are calculated for stations within 20 degrees of an event that is 30km deep or shallower . It would be of great benefit to event screening if all events that could possibly originate in the crust had regional amplitude measures. So it is proposed to extend calculations of amplitude measurements to all events whose 95% depth interval falls with the crust (0-35km depth for Iaspei91).

2.3.2 Seismological Evaluation

In many studies it has been shown that events in the REB are biased deep in comparison to regional bulletins. Therefore many events most probably originating in the crust have sub-crustal REB depths, resulting in no regional amplitudes being calculated. So to take account of this it would be appropriate to extend calculations of amplitude measurements to all events whose 95% depth interval falls with the crust (0-35km depth for Iaspei91). This would result in a 20% increase in the number of events with regional amplitudes.

An evaluation on the worthiness of this extension was performed by analysing the number of new regional phase amplitude measures that had a SNR > = 2. 137 out of 176 Pn amplitudes, 10/175 Pg amplitudes, 57/166 Sn amplitudes and 14/131 Lg amplitudes exceeded SNR=2. Although many of the new regional phase amplitudes may not be related to a regional phase at all, the high percentage of Pn amplitudes with SNR > 2 indicates that many would be, and would be able to contribute information to event screening.

2.4. Fix bug in beam.c

2.4.1 Requirement

Fix a bug in routine beam.c

2.4.2 Solution

Remove the line of code that tapers the normalization function for `nelem = 1`. The end result is that anomalous beams are now not formed. Another approach that may be considered here which will have the same effect, is to mask the normalization function during the time intervals where the tapering is imposed.

2.4.3 Example

Figure 7a shows the raw seismic data recorded at MBC (channel bz) from a REB event off the north coast of Greenland on 29/03/1996. A 6 second datadrop is visible, starting about 23 seconds after the initial onset. The corresponding normalization function (fig. 7b) is masked out (value = 0) during this time. Currently, both the raw data and the normalization function are tapered (figures 7c & 7d) before the data is filtered (fig. 7e) then squared (fig. 7f). For an array this process is repeated over all the elements to form squared beams and normalization beams.

The squared beam is then normalised by dividing the squared beam by the tapered normalization beam function, except when the normalization function equals zero (fig. 7g). In this case, a single channel beam, the tapered normalization function is that depicted in fig. 7d, and the functions becomes very small just before it reaches zero. The filtered trace at that point has a significant amount of energy (since the tapering process can't eliminate the generation of all the spurious effects of filtering), so the resulting beam becomes anomalously large (fig. 7g). For arrays this is not so much a problem as these anomalies are minimised by summing over many channels.

<u>However</u> if the normalization function is not tapered (use fig. 7b), this problem is removed and the correct squared beam is formed (fig. 7h).

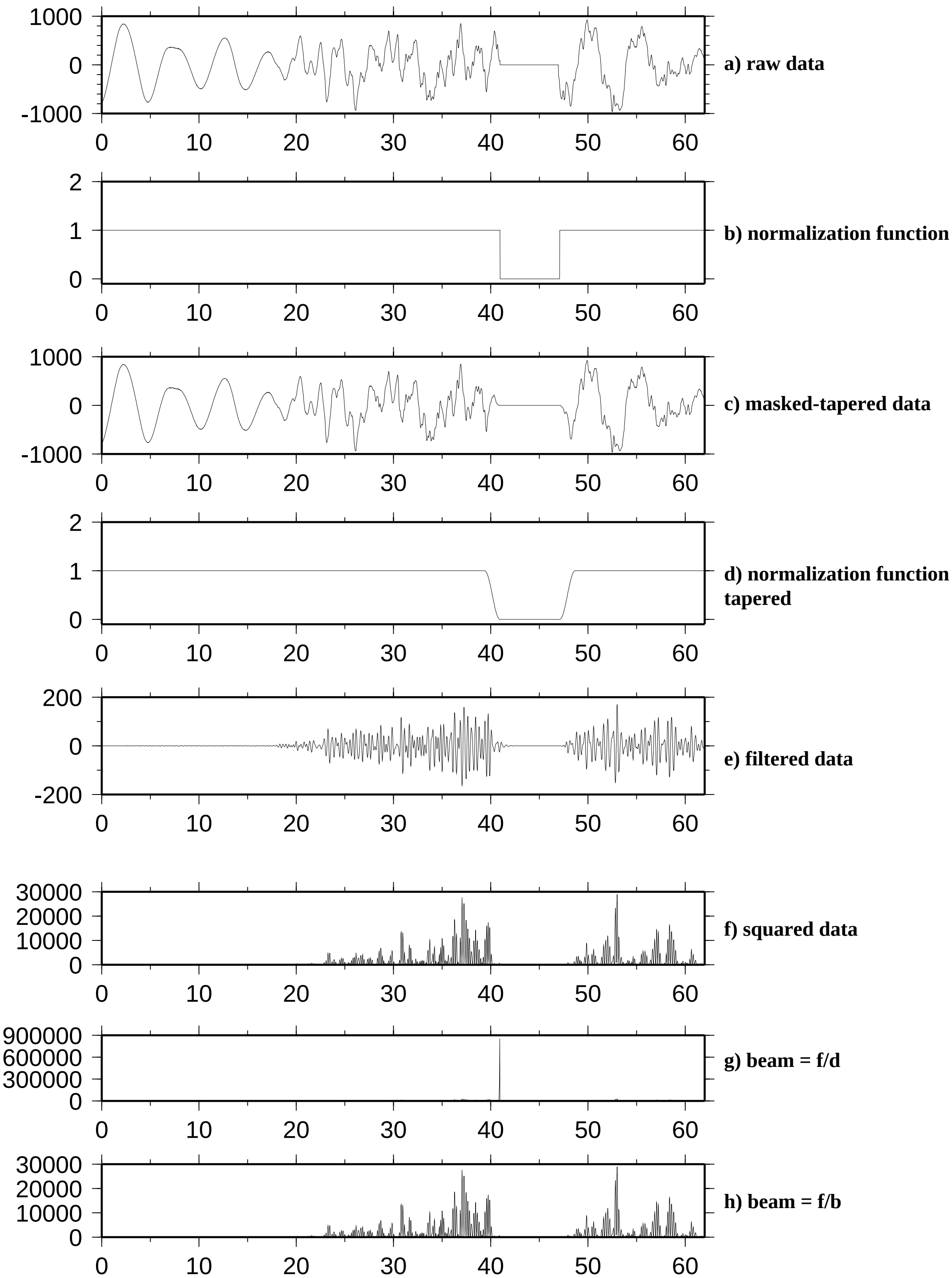

Figure 7: Seismogram recorded at MBC from an event near Greenland

3. References

Hansen, R. A., F. Ringdal, P. G. Richards (1990). The Stability of RMS Lg Measurements and Their Potential for Accurate Estimates of the Yields of Soviet Underground Nuclear Explosions, Bull. Seis. Soc. Am., 80, 2106-2126.

Mayeda, K. (1993). Mb (LgCoda): A stable Single Station Estimator of Magnitude, Bull. Seis. Soc. Am., 83, 851-861.

Nuttli, O. W. (1973). Seismic Wave Attenuation and Magnitude Relations for Eastern North America, J. Geophys. Res., 78, 876-885.

Nuttli, O. W. (1986a). Yield Estimates of Nevada Test Site Explosions Obtained from Seismic Lg Waves, J. Geophys. Res., 91, 2137-2151.

Nuttli, O. W. (1986b). Lg Magnitudes of Selected East Kazakhstan Underground Explosions, Bull. Seis. Soc. Am., 76, 1241-1251.

Patton, H. P. (1988). Application of Method to Estimate Yield of Nevada Test Site Explosions Recorded on Lawrence Livermore National Laboratory's Digital Seismic System, Bull. Seis. Soc. Am., 78, 1759-1772.

Ringdal, F. (1983). Magnitudes from P Coda and Lg Using NORSAR Data, in Norsar Technical Summary, 1 October 82 - 31 March 83, NORSAR Sci. Report. No. 2-82/83, NTNF/NORSAR, Kjeller, Norway.

CCB-PRO-98/07: PIDC 6.0: Event Characterization, 6 March 1998

CCB-960702: To incorporate routine estimation of event characterization parameters into IDC operations, CCB Memo, July 1996.

Appendix B: Software and par file changes

In revising the procedures for DFX event-characterization amplitude measurements, three par files, a scheme file and two source files were modified. The changes are described below:

1. DFX-evch.par

1.1 Change amplitude processing depth from 30 to 35km:

```
evch-arrivalamp-max-depth = 30 35
evch-originamp-max-depth = 30 35
```

1.2 Add 4 arguments to evch-originamp-amprec-list:

```
Evch-originamp-amprec-list=sigPn,noiPn,sigPg,noiPg,sigSn,
noiSn,sigLg,noiLg,sigPmax,noiPmax,sigSmax,noiSmax
```

2. evch-amp.par

This is a large file, so only comments on the additions are described:

For the 5 new frequency bands the following are now calculated:
amplitudes in predicted Lg windows (signal and noise)
amplitudes for the observed regional phases (signal and noise)

For the current frequency bands (6 in total) the following are now calculated:
Pmax (signal and noise)
Smax (signal and noise)

3. evch-ti.par

The old evch-ti.par file:

```
#!BeginTable tirec
|name     |rmin|rmax  |sphase|sgv|lead|ephase|egv |lag|
intsPn     0    360    Pn       -1  8.0  -       6.4 0
intnPn     0    360    Pn       -1  13.0 Pn      -1  8.0
intsPg     0    360    -        6.3 0    -       5.8 0
intnPg     0    360    -        6.4 0    -       6.3 0
intsSn     0    360    Sn       -1  5.0  Sn      -1  15.0
intnSn     0    360    Sn       -1  10.0 Sn      -1  -5.0
intsLg     0    360    -        3.7 0    -       3.0 0
intnLg     0    360    -        3.8 0    -       3.7 0

obs_s      0    360  -          -1  5.0  -       -1  15.0
obs_n      0    360    -        -1  15.0 -       -1  -5.0
intsFm     0    360    -        -1  0.0  -       -1  5.0
intnFm     0    360    -        -1  11.0 -       -1  -1.0

evch-reg   0    20     -        -1  50   -       2.5 50
evch-tele  20   360    -        -1  50   P       -1  70
```

has been changed to:

```
#!BeginTable tirec
|name     |rmin|rmax  |sphase|sgv|lead|ephase|egv |lag|
intsPmax   0    2.999  Pn       -1  8.0  -       5.8 5.0
intnPmax   0    2.999  Pn       -1  13.0 Pn      -1  -8.0
```

```
intsSmax1  0    1.499  Sn      -1  5.0  -      3.0 5.0
intsSmax2  1.5  2.999  Sn      -1  10.0 -      3.0 5.0
intnSmax1  0    1.499  Sn      -1  10.0 Sn     -1  -5.0
intnSmax2  1.5  2.999  Sn      -1  15.0 Sn     -1  -10.0
intsPn     3    360    Pn      -1  8.0  -      6.4 0
intnPn     3    360    Pn      -1  13.0 Pn     -1  8.0
intsPg     3    360    -       6.3 0    -      5.8 5.0
intnPg     3    360    -       6.4 0    -      6.3 0
intsSn1    3    6.999  Sn      -1  10.0 -      3.8 0
intsSn2    7    360    Sn      -1  20.0 -      3.8 0
intnSn1    3    6.999  Sn      -1  15.0 Sn     -1  -10.0
intnSn2    7    360    Sn      -1  25.0 Sn     -1  -20.0
intsLg     3    360    -       3.7 0    -      3.0 0
intnLg     3    360    -       3.8 0    -      3.7 0

obs_s1     0    4.999  -       -1  1.0  -      -1  5.0
obs_s2     5    5.999  -       -1  1.0  -      -1  10.0
obs_s3     6    360    -       -1  1.0  -      -1  15.0
obs_n      0    360    -       -1  6.0  -      -1  -1.0
intsFm     0    360    -       -1  0.0  -      -1  5.0
intnFm     0    360    -       -1  11.0 -      -1  -1.0

evch-reg   0    20     -       -1  50   -      2.5 50
evch-tele  20   360    -       -1  50   P      -1  70

#!EndTable
```

4. DFX-evch.scm

New function query-for-dborigerr-by-orid

```
(define (query-for-dborigerr-by-orid orid origerr-table)
  (let ((query
        (string-format
         "SELECT * FROM %s WHERE orid = %d"
         (list origerr-table
               orid))))
   (query-for-container (say-dborigerr-object-class) query)))
```

Additional lines added to function process-origins (obtaining and checking for origerr entry)

```
(dborigerr nil))

;;   Check for origerr entry
;;
(set! origerr-table (mstspar "origerr-table"))
(set! dborigin-con (query-for-dborigerr-by-orid
        (extract-gobj-attr dborigin "orid") origerr-table))
(if (container-empty? Dborigerr-con)
   (throw-tag-error 'major-processing-error
    (string-format "Error: no origerr entry found for orid %d"
    (list (extract-gobj-attr dborigin "orid")))))
(set! dborigerr (nth-container 0 dborigerr-con))
```

Modification of arguments in function process-origin-for-initsite

from : `process-origin-for-initsite initsite dborigin`

to: `process-origin-for-initsite initsite dborigin dborigerr`

Replace the following lines in function process-origin-for-initsite

```
(if (and (<= depth max-depth)
        (> delta min-delta)
        (<= delta max-delta))
with
(if (or (and (> szz 0)
             (<= (- depth (* 2 (sqrt szz))) 35)
             (> delta min-delta)
```

```
          (<= delta max-delta)
          (> depth max-depth)
     (and (<= depth max-depth)
          (> delta min-delta)
          (<= delta max-delta)
```

5. cvar_ftns.c

Add line var_set ("origerr-table", "origerr");

6. beam.c

hash out line 347: `qc-taper-segments (elnorm, npts, mask, 1, 0);`

Appendix C

Integration Test Plan and Report

Plan

A simple plan was developed to test the changes to the existing event characterization modules, and was as follows:

1. Run EVCH modules for all REBs that are available in the first test period. Mike Skov indicated that only 2 REBs may be available during this period. It was judged that this would sufficient.

2. Check the runtime performance of EVCH. This to include both the processing time and examination of any resulting errors.

3. Check the measurements calculated and compare them to that expected.

Report

Two REBs were available in the first test period, data days 2000094 and 2000095. As part of the post REB processing tests, the event characterization modules were run.

The event characterization modules are run in 4 hour time blocks, and the run-time statistics for each block for the 2 datadays is given in Table C1. Around 70 stations were set-up on the testbed for testing, and there was a total of 95 events in the 2 days.

	no. events	0-4	4-8	8-12	12-16	16-20	20-24	total
2000094	52	418	508	1250	1034	991	103	4304
2000095	43	259	481	277	752	499	242	2510

Table c1: Processing time (in seconds) for each four hour blocks for datadays 2000094 and 2000095.

All events were successfully processed with no run time errors. Total processing time was minimal as expected, and did not differ significantly to previous tests (see CCB-PRO-98/07).

Although the number of measurements calculated for 2 data days is low, it is clearly seen on figures 8-10 that the measurements are within the expected bounds, which are fully described in Appendix A.

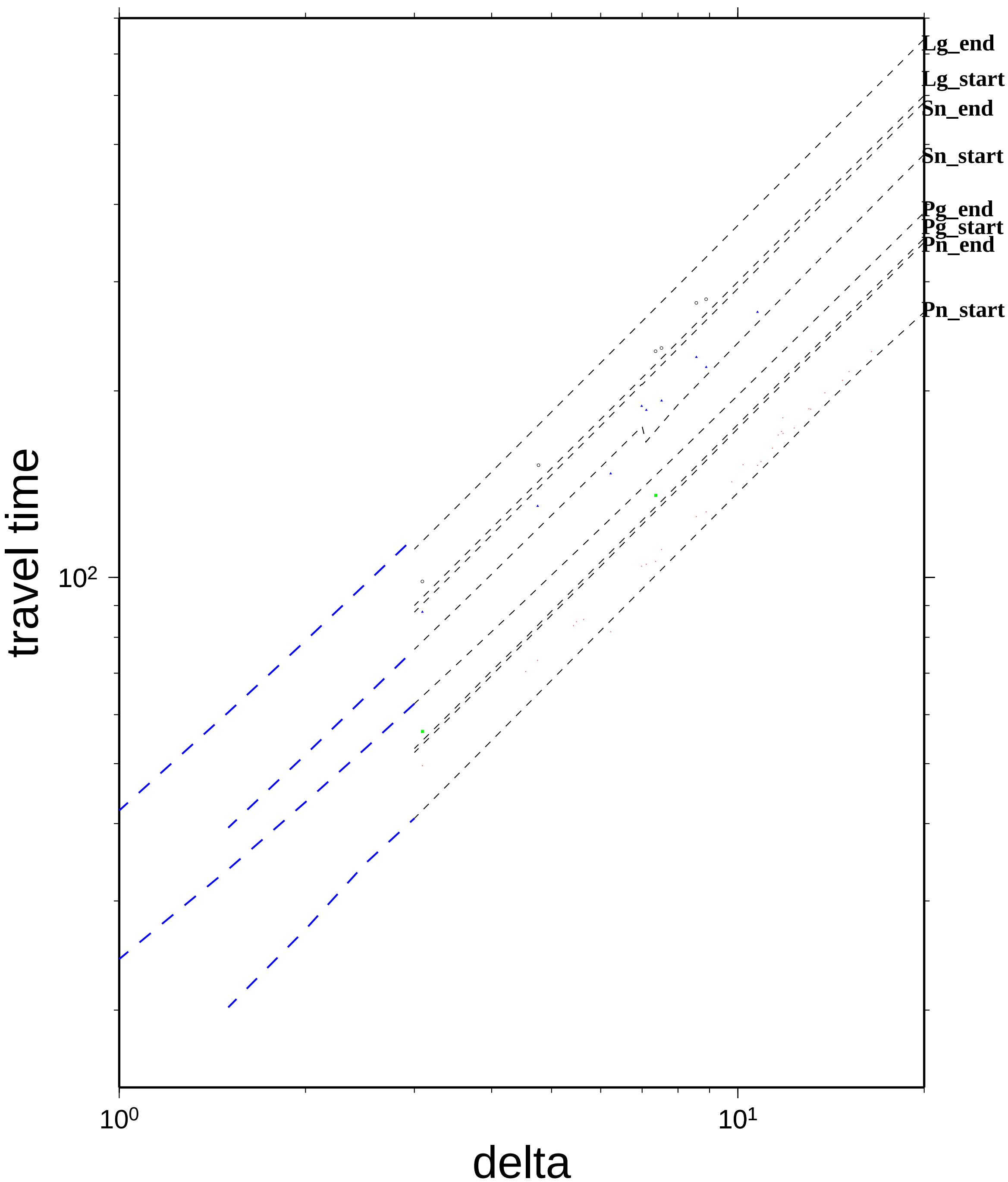

Figure 8: New Predicted time windows of regional phases plotted as a function of travel time versus distance, overlayen by the analyst picks: Pn (red), Pg (green), Sn (blue) and Lg (black). The data span days 2000094 and 2000095.

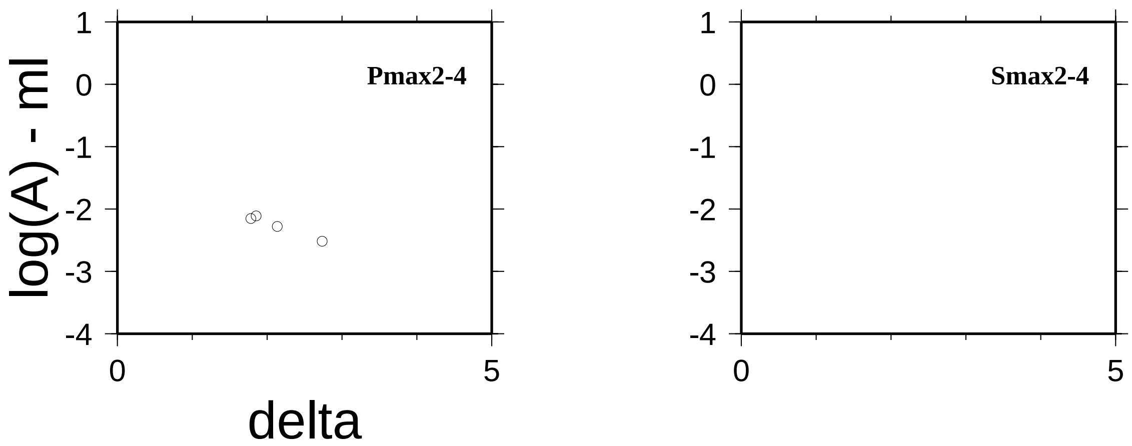

Figure 9: Plots of log(amplitude) - ml versus distance for theoertical Pmax and Smax amplitudes in frequency band 2-4Hz, with SNR > 2. The data span days 2000094 and 2000095.

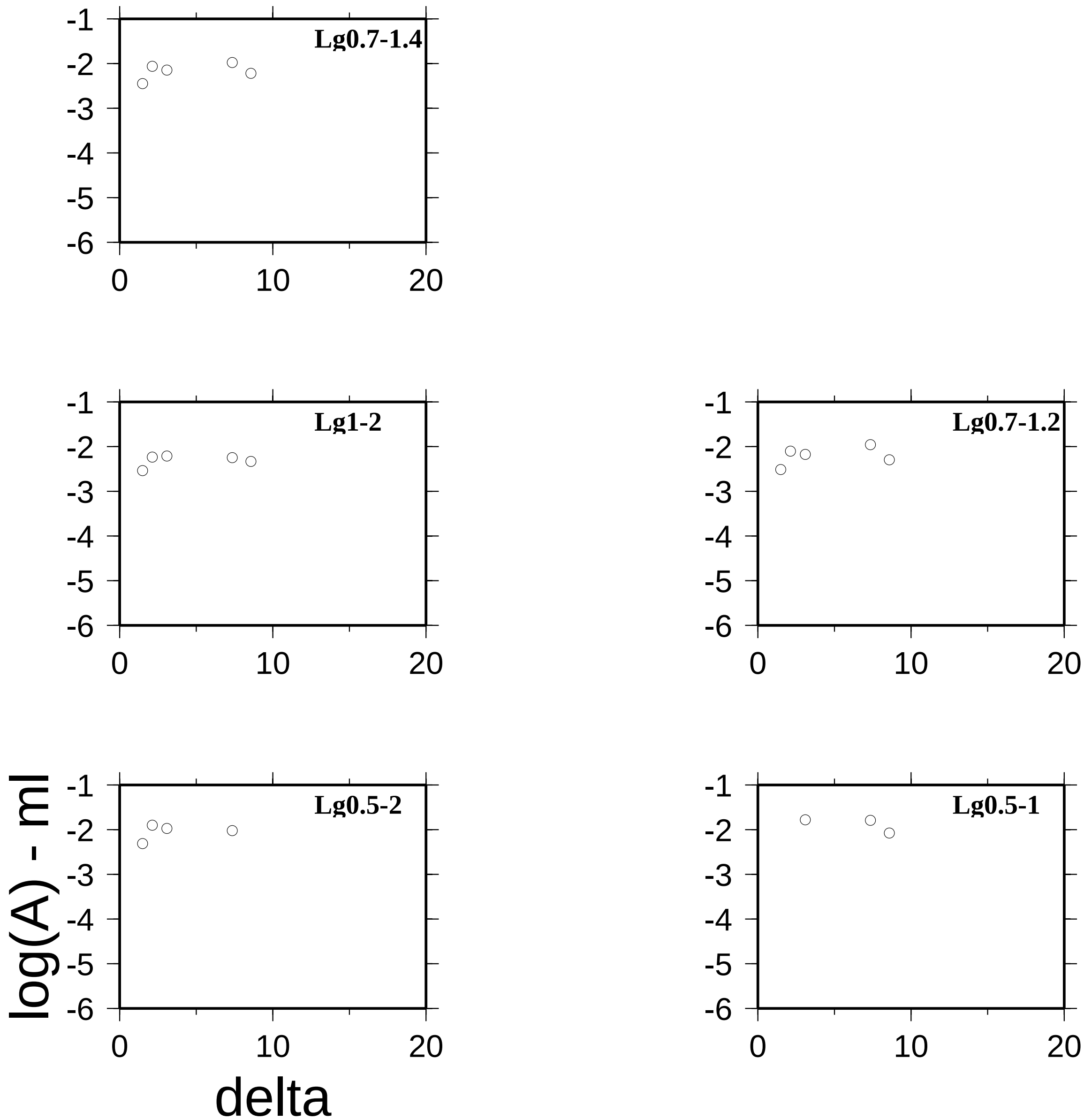

Figure 10: Plots of log(amplitude) - ml versus distance for observed Lg, in frequency bands 0.5-2, 0.5-1, 1-2, 0.7-1.2 & 0.7-1.4Hz, with SNR > 2. The data span days 2000094 and 2000095.